Lighthouses and Ecosystems: Conditions for payment for ecosystem services schemes based on Coase

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Abstract: Payments for ecosystem services (PES) have become popular in both theory and practice. The use of market based instruments is welcomed by some, and rejected by others in the literature. Yet, we lack knowledge about the specific conditions under which markets are apt for the provision of ecosystem services. This paper contributes to the elaboration of such conditions for PES. Coase's work on public goods, his analysis of lighthouses in economics (1974), is compared to ecosystem services. Ecosystem services are often public goods for which economists suggest state provision. The lighthouse in economics serves as an illustration for public good (non-excludable and non-rival). Coase (1974) shows that contrary to conventional economic wisdom lighthouses were privately and profitably run by Trinity House in British history. Here, I take Coase's findings on lighthouses and compare them to the provision of ecosystem services. This article concludes that markets can work if ecosystems share properties with lighthouses. If not, other governance option should be favored.

Keywords: Payments for Ecosystem Services, PES, Coase, Environmental Policy, Economic Instruments

JEL-Classification: B31, D63, H23, Q50, Q56, Q57, Q58

1. Introduction

Amongst the instrumental tool box of policies for sustainable development, Payments for Ecosystem Services (PES) have increasingly attracted development practitioners, policy makers, and scholars alike (Braat & de Groot, 2012). Such payment instruments are implemented in developing and industrial countries for various ecosystem services (Braat, 2013; Sattler &

Matzdorf, 2013)[1]. PES schemes pursue incentive-based regulation and provider-gets-schemes (Jack et al., 2008; Mauerhofer et al., 2013): Instead of making the polluter pay, PES reward for the provision of beneficial ecosystem services. In the language of economists, such ecosystem services are positive externalities.

The Millennium Ecosystem Assessment (2005) concludes that many ecosystem services are in decline, despite their relevance for human well-being and their importance for the environment. Without PES, many argue, ecosystem services are not sufficiently supplied by the market due to their (at least local or regional) public goods character and the missing market prices (Carpenter et al., 2009, pp. 1308-1309): The provider has no (market) incentive to supply these necessary ecosystem services for free. Thus PES, the argument goes, to incentivice farmers, foresters, apiculturists, and others to provide ecosystem services not yet paid for by the market. Payments for ecosystem services are voluntary payment schemes between an ecosystem service buyer and seller, conditional upon specific natural resource management practices (see figure 1).[2]

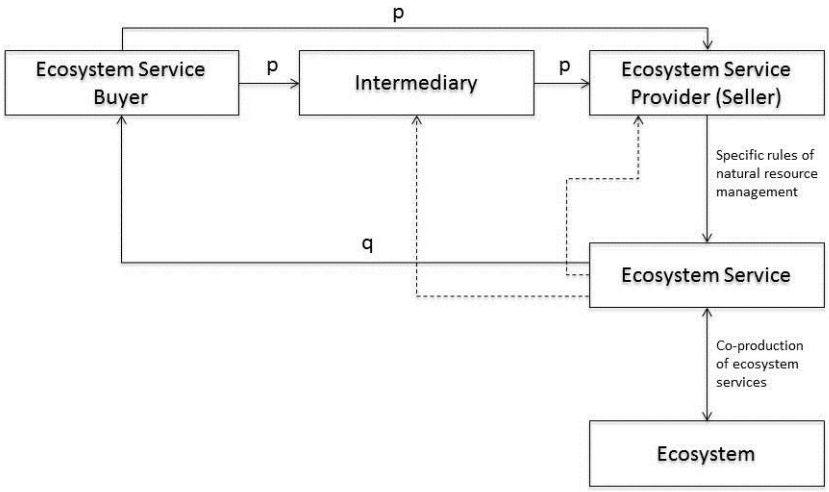

Figure 1 Flow diagram of Payment for Ecosystem Services (PES) scheme. PES are voluntary payments (p) between a service buyer and provider, conditional upon natural resource management practices for the provision of a quantity (q) of ecosystem services. The dotted arrows indicate that ecosystem services can also benefit the intermediary and the provider. (Own figure)

In the academic community around ecosystem services, some argue for (Engel et al., 2008; Wunder, 2005) some argue against (Kosoy & Corbera, 2010; McAfee, 2012a, 2012b; Muradian & Rival, 2012) the use of markets and payments to provide ecosystem services. Successful and well-documented PES cases are in place, where effective provision of ecosystem services is realized due to payment schemes (Engel et al., 2008; Farley et al., 2010; Schomers & Matzdorf, 2013).

Yet, we lack specific knowledge under which conditions markets can be used effectively for ecosystem service provision (Kemkes et al., 2010). Muradian and Rival (2012, p. 99) "stress that economic incentives may, under specific circumstances, contribute to improving the governance regimes of natural ecosystems." In this paper, I specify such circumstances under which markets are an appropriate policy tool for ecosystem services by using Coase's analysis of the lighthouse in economics (1974). The paper argues that particular criteria of ecosystem services render apt market solutions and payment schemes. If these conditions are not in place, other governance schemes than markets are more appropriate.

Following Coase (1974), this article applies his study of lighthouses to ecosystem services. The guiding research question is: when comparing lighthouses and ecosystem services, under what conditions are markets an effective policy tool for the provision of ecosystem services? In this article, I relate ecosystem services (section 2) to lighthouses (section 3). Along a set of specific criteria, the article develops conditions under which markets can efficiently be used for the provision of ecosystem services (section 4). This leads to specific governance proposals for different ecosystem service properties (section 5). The last section (6) concludes.

The argument developed here for governance structures of ecosystem services contributes to the economics of sustainable development (Remig, 2015). The paper also serves as a boundary object – parallel to the term ecosystem services itself (Abson et al., 2014) – for two communities: to the economists and economic historians, it provides an application of their work and thinking to ecosystem services. To the natural science communities of ecosystem services, it specifies interlinkeages with social science colleagues.

2. Ecosystems and ecosystem services are different than conventional commodities

The interest for ecosystem services has risen only recently within the scientific epistemic community, even though we find in the literature the ecosystem services concept in much older sources (Gomez-Baggethun & De Groot, 2010; Gómez-Baggethun et al., 2010). For the purpose of this article, we can understand ecosystems as complex adaptive systems (Levin, 1998), in

contrast to the well-ordered structure of a simple system. Thus, Holling and Sanderson (1996, p. 63) compare the functioning of ecosystems to that of jazz band:

"The cycles are all operating concurrently, influencing one another. They are rhythms within rhythms, providing not the static structures of a well-oiled machine shop, clanking and vibrating at a myriad of frequencies, but rather those of a jazz band, building rhythms and riffs around each other, coalescing into both short and long rhythmic structures around islands of rhythmic discord."

This section defines ecosystems and their services (2.1.). Their specific properties make them a special case of commodities. Thus, trading ecosystem services on markets bears difficulties (2.2.).

2.1. Defining ecosystems and ecosystem services

Different definitions of ecosystems exist and a very good overview has been provided elsewhere (Jax, 2006, 2007). Figure 2 illustrates what an ecosystem is and how it relates to ecosystem services.

Costanza and Folke (1996, p. 13) provide a very useful definition: "An ecosystem consists of plants, animals, and microorganisms which live in biological communities and which interact with each other and with the physical and chemical environment, with adjacent ecosystem, and with the atmosphere." The history of the term ecosystem can be traced back to Tansley (1935, p. 299): an ecosystem is "the whole *system* (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome – the habitat factors in the widest sense (emphasis in original)." Interestingly, already in this first definition of ecosystems, the systemic perspective is underlined by Tansley.

Ecosystems as described above provide ecosystem functions, which can be turned into services for the benefit of humans (see also Figure 2). The concept of ecosystem services has become particularly prominent with the Millennium Ecosystem Assessment (MEA) (Braat & de Groot, 2012; Norgaard, 2008). "Ecosystem services are the benefits people obtain from ecosystems" is the definition given by the Millennium Ecosystem Assessment (2005, p. 40). Four categories of ecosystem services are identified in the MEA: provisioning, regulating, cultural, and supporting ecosystem services (see figure 2). Imagine walking through a forest: during such a walk, you can encounter and enjoy all four categories of ecosystem services. The forest ecosystem, for example, provides wood (the products from the ecosystem), is important for air quality and climate regulation (the regulating benefits from the ecosystem processes), people can enjoy its aesthetic beauty wandering through it (the non-material, cultural benefits), and it contributes to soil formation and many other

important natural cycles (indirect supporting services to people over the long term).

The relationship between ecosystem services and human well-being is complex. Haines-Young and Potschin (2010) conceptualize the relationship as a cascade, in which biophysical structures and processes are turned into functions, services, and finally benefits. In a further refinement of this cascade, Spangenberg et al. (2014) highlight the importance of human agency in the management and provision of ecosystem services. The co-production aspect of ecosystem services, which depend on both nature and society, is thus emphasized.

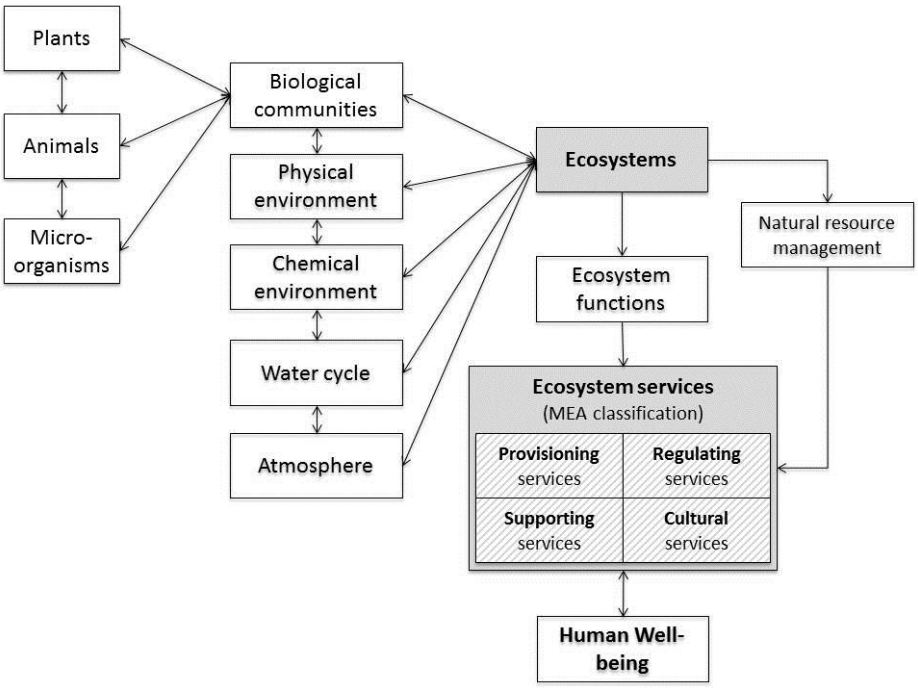

Figure 2 Relating ecosystems, ecosystem services, and human well-being. This figure illustrates the constituent parts of an ecosystem and their relations to ecosystem services. The ecosystem definition is based on Costanza and Folke (1996). The ecosystem service classification is taken from the Millennium Ecosystem Assessment (MEA). (Own figure)

Ecosystem services can be both stock-flow and fund-service resources (Farley & Costanza, 2010). The stock-flow and fund-service model has been developed by Georgescu-Roegen (1971) to highlight the different properties of natural resources. Wood and timber, for example, are stock-flow resources,

because they are transformed in the production process. They are used up, can be stockpiled and can be used at any rate desired. Fund services, such as aesthetic beauty of the forest, are worn out by the production process (for example the extraction of wood). They cannot be stockpiled and produce their services at a fixed rate. Ecosystem services can provide both, stock-flow and fund-service resources for human benefits.

The rhetoric of ecosystem services has been criticized by some. They argue that the linguistic turn from ecosystem *functions* to ecosystem *services* has implications for how we perceive the environment (see for exmaple McCauley, 2006). While the term function is more oriented along the biological components and ecosystem processes, the term services already places ecosystems functions in realm of markets (Peterson et al., 2010).

2.2. Problems when the environment becomes a commodity

Ecosystems and their services, as defined in the above section, are a specific form of commodities. They are not commodities like those that economists usually deal with – and that is why the environment can be considered a challenge to the economic theory (Beckenbach, 1992) . Vatn (2000) provides a detailed account of the complexities that occur when the environment is transformed into a commodity, when nature is traded on the marketplace.

Economists deal in their discipline with goods and services that are allocated on markets. The environment and its services, on the contrary to conventional goods and services, have specific properties, which complicate their commodification. There are some markets for environmental goods, but many of those ecosystem services beneficial to humans are not traded on the market (thus PES, the argument goes). If traded on markets, the prices for ecosystem services not necessarily reflect their scarcity. Pricing, based on marginal analysis, can become obsolete when ecosystems do not behave like conventional production entities in economic textbooks (Farley, 2012).

Ecosystem services are co-produced by humans and the environment (Rammel et al., 2007). The production function of conventional market goods involves labor, capital, and resources. Ecosystems, evolutionary and dynamic systems, are in addition involved in the production of ecosystem services. The production of the ecosystem thus does not only depend on labor and capital but also on a function of the ecosystem dynamics. Whereas control over labor and capital is possible, the management of ecosystem services is much more complex.

Since Coase (1960), economists also include property rights in their analysis. On the market place, the economic exchange is a transfer of property rights from the buyer to the seller (see also figure 1). If property rights are not well defined, selling, buying, and trading become difficult. The issue of property rights is also important in the management of natural resources

(Bromley, 1978; Ostrom, 2003). With regards to ecosystems, property rights structures are often unclear. This is due, for example, to the many interwoven property rights regimes (Schlager & Ostrom, 1992). Even though property rights may be clearly defined in some cases, difficulties can emerge when trying to identify the source of ecosystem service and the specific parts that contribute to the service in question (think of different forest patches and their contribution to CO2 uptake, water regulation, or aesthetic beauty – which tree accounts for which service?).

Ecosystems as complex adaptive systems involve many processes at different time and geographical levels (Holling, 1994b). Some of these processes are beyond human controllable. If we assume bounded rationality, we are limited in our understanding in the management of ecosystem services (Foxon, 2006). Managing ecosystems based on resilience, instead of stability, echoes the assumption of bounded rationality (Simon, 1986). "Flowing from this would be not the presumption of sufficient knowledge, but the recognition of our ignorance; not the assumption that future events are expected, but that they will be unexpected." (Holling, 1973, p. 21) Discontinuities and tipping points (Lenton et al., 2008; Schellnhuber, 2009) in ecosystems make their management difficult. Marginal analysis, in such a context, fails to incorporate all these dynamics. What is valid for the production of one unit of ecosystem services, does not necessarily apply to the production of the next unit. Gunderson and Holling (2002) analyzed such ecosystem dynamics and related them to institutions and social learning.

This is in contrast to the conventional economic worldview. The *homo oeconomicus*, a fully rational and fully informed person, maximizes for utility under given budgetary constraints. The optimization logic is also applied to ecosystems where the focus is on maximum sustainable yield. Yet, to manage for an optimal sustainable yield does not mean to manage the resource sustainably. For optimization management practices do not reflect the complexities of natural cycles. Rather, ecosystems should be managed for resilience and sustainability (Holling, 1973) so that they maintain their functions and services despite external shocks and stresses. The focus on maximizing one sort of value, social welfare in economics for example, has become a dominant paradigm in economics. Economists also apply this paradigm to the environment: "The overriding temptation of modern human societies is to maximize for a narrow range of values, so that maximum sustainable yield of forest or fishery or rice field forces managers to ignore the importance of long-term successional dynamics, in favor of short-term output." (Holling & Sanderson, 1996, p. 77)

Even though there are some markets for ecosystem services – think of the entrance fee you pay for visiting a natural reserve or the price for fire wood– there are many ecosystem services for which no markets exist. For goods traded on markets, prices are easily identified when supply and demand meet.

When goods are not traded on markets, it is much more complicated to come up with prices (Farley, 2012). Economists have conceived many solutions to the valuation of environmental goods and have invented methods that allow them to obtain prices for goods not traded on markets (Hanley et al., 1995; Parks & Gowdy, 2013; Spash & Vatn, 2006).

However, the valuation of environmental goods has been criticized because in the process of valuation and the reduction to one monetary figure, many characteristics of ecosystem services are lost (Parks & Gowdy, 2013). "Efforts to derive hypothetical values for the complex and interrelated attributes of the environment, a process that compresses this complexity into a simple metric of monetary values, results in a non-trivial loss of information." (Vatn & Bromley, 1994, p. 130) Gomez-Baggethun and Ruiz-Perez (2011) identify the risk that monetary valuation leads to commodification of ecosystem services, disregarding both equity concerns and environmental conservation.

This commodification process of natural resources has become criticized. With regard to ecosystem services, Kosoy and Corbera (2010) identify a "commodity fetishism" that occurs due to the expansion of the market sphere to the environment. In a historical analysis of the transition of the 19th to the 20th century, Polanyi (2001 [1944]) provides an account of these dynamics: the expansion of the market sphere has led to the fictitious commodification of specific goods like labor, money, and land that used to be outside of market realm. Polanyi and his analysis of the dynamics between markets and society can be seen as a precursor of the sustainability debate (Göpel & Remig, 2014).

The governance structure around the provision of ecosystem services does not only rely on markets but also includes incentives, rewards, multi-layered and hybrid governance structures (Muradian & Rival, 2012). Sattler and Matzdorf (2013) show how different the reality of existing PES schemes is with regards to ecosystem services, buyers, implementers, intermediaries, and others involved. An institutional analysis of PES schemes has been provided by Vatn (2010).

Extending the market logic to the environment is – given the properties of complex adaptive systems – not as evident as it might sound. In addition, "pricing is not sufficient to ensure informed and coherent collective choices about environmental goods and services." (Vatn & Bromley, 1994, p. 145) An integrated management of all dimensions – the environmental, the economic, and the social one – is required for complex adaptive systems (Holling, 2001). Economists argue for the allocation of resources by markets. In the case of ecosystem services, this procedure is more complex than for conventional commodities. The economic framework is less apt to grasp these challenges and has been broadened to the ecological and social sphere under the "big tent" of ecological economics (Remig, 2015).

3. On Coase, economics, and lighthouses

Economists tell stories (McCloskey, 1983, 1990). A good storytelling makes use of metaphors (McCloskey, 1995). To illustrate what public goods – non-rival and non-exclusive – are economists use the lighthouse metaphor. Since markets underprovide public goods, economists often argue for state intervention in such cases. Coase (1974) challenged this understanding. The current discussion of PES references Coase (1960), but misses his essential points (3.1.). Here, I apply Coase's work on public goods to ecosystem services (3.2.).

3.1. Current PES discussion misses Coase's points

Coase (1960) on social costs is often referenced in the PES literature (Engel et al., 2008; Mauerhofer et al., 2013; Sattler & Matzdorf, 2013; Schomers & Matzdorf, 2013). Yet a link to his work on lighthouses and public goods is missing so far. In the literature, it is argued that PES put into practice the so-called "Coase theorem": assuming no transaction costs and well-defined property rights, negotiations between polluter and pollutee yield efficient outcome regardless of the initial allocation of property rights.[3] Payments for ecosystem services are thus conceived as "Coasean solution" to environmental externalities or as "Coasean-type" policy instruments. The presumably Coasean-model, i.e. market-based approaches, is opposed to the Pigouvian-approach, which aims to internalize external costs via taxes and subsidies. How to regulate externalities is a central question in the economics of sustainable development (Remig, 2015).

A pitfall with such references to Coase, however, is that misperceptions persist about his view on economics and economic theory (McCloskey, 1998). Some argue that PES put into practice the "Coase theorem" (see for exmaple Engel et al., 2008; Mauerhofer et al., 2013). Yet, Coase never formulated such a theorem (it was George Stigler) and at many occasions argued against (Coase, 1981, 1988; McCloskey, 1998; Medema, 2011a).[4]

Coase himself asserted at many occasions that his ideas have not been taken up correctly by economists: "My point of view has not in general commanded asset, nor has my argument, for the most part, been understood." (Coase, 1988, p. 1) Despite being among the most cited economists and Nobel Laureate,[5] "most economists are unfamiliar with Coase's critiques and with the alternative approach that he is advocating, and are content, instead, to conveniently lump him into the Chicago mold." (Medema, 1995, p. 16)[6]

These misperceptions about Coasean economics have implications for the academic discussion and the political practice of PES (see for example Engel et al., 2008, p. 665). "The dominant conceptual approach towards PES is derived from Coasean economics, and it conceives PES primarily as a way to

improve economic efficiency." (Pascual et al., 2010, p. 1237) This dominant paradigm of PES is contested. Muradian and Rival (2012, p. 96), for example, reject the Coasean reference: "We argue that more useful insights for the management of ecosystem services can be derived from the literature on institutional arrangements for governing common-pool and public resources than from the literature on Coasean approaches to resolve environmental externalities."

The references to Coase in the PES literature are neither productive for a better understanding of PES nor do they provide an appropriate classification for different PES schemes. The aim of this article is thus to deduce from the comparison of Coase's work on lighthouses to ecosystem services a set of ecosystem properties, in which cases a market governance mode such as PES work.

3.2. Coasean analysis of the lighthouse in economics

Coase argued that economics should study the working of the economic system (Coase, 1998; Coase, 1960, 1988, 1992). We live in a world where transaction cost are positive and matter (Coase, 1937, 1960). In PES schemes, transaction costs are quite important (Schomers & Matzdorf, 2013; Vatn, 2010). The issue of property rights and their relevance for the outcome of policy options also relates to the pioneering work of Coase (1960, 1988). The question of public goods and their governance structure is central in the article on the lighthouse in economics. Here, Coase (1974) undertakes an empirical analysis about the working and operation of the British lighthouse system.

The problem of providing goods not yet traded on the market is well known to economists. The lighthouse is a metaphor for such a public good. Economists conceptualize lighthouses as *non-rival* (navigational light consumed by one ship does not diminish another ships' possibility to also benefit from the guiding light) and *non-exclusive* (the lighthouse keeper cannot exclude ships from using the light for navigation). State intervention is claimed necessary to align private and social marginal costs for the optimal provision of public goods.

Yet the journey from lighthouses in textbooks to lighthouses on coastlines, from theory to practice, from "blackboard economics" to "humanomics"[7], can bear surprises: contrary to conventional economic wisdom, Coase (1974) showed that private lighthouses run by Trinity House, profitably and efficiently occurred in history. There were indeed market structures providing navigational information by lighthouses in Britain. Thus, Coase concluded that a case-by-case approach is necessary for determining which governance structure applies best to public goods. Sometimes state intervention is required and beneficial, sometimes not.

The conventional economic wisdom uses the lighthouse as an illustration for a pure public good. To Coase, this conclusion is "blackboard economics," because the economists did not undertake an actual study of the working of the lighthouse system:

"The early history shows that, contrary to the belief of many economists, a lighthouse service can be provided by private enterprise. In those days, shipowners and shippers could petition the Crown to allow a private individual to construct a lighthouse and to levy a (specified) toll on ships benefitting from it. The lighthouses were built, operated, financed and owned by private individuals, who could sell the lighthouse or dispose of it by bequest. The role of the government was limited to the establishment and enforcement of property rights in the lighthouse." (Coase, 1974, p. 375)

Coase argued that public goods not necessarily require state intervention. The state has of course its role in defining and ensuring the institutional setting, but the point is that the lighthouse system thrived and was profitably run by a private company, Trinity House. Coase provides counterfactual evidence to the economists' claim that public goods require state provision. There are possibilities to provide public goods through markets.

Coase's argument has been discussed in the literature. Van Zandt (1993) argues that Coase's distinction of private and state enterprise is flawed. Bertrand (2006) revisits the historical evidence and concludes that the British lighthouse system was a mixed one, in which private and state actors provided the public good. She also finds that the lighthouse system was neither as efficient nor as appropriate for the provision as Coase argues. There are also authors in defense of Coase's analysis, by arguing against both Van Zandt and Bertrand (Barnett & Block, 2007; Block & Barnett, 2009). Bertrand (2009) convincingly replies to the arguments.

Despite the controversy about Coase's treatment of lighthouses, there is an interest in pursuing his analysis: "The debate initiated by Coase's article goes well beyond the lighthouse issue. It involves the respective definitions of private and public production, the role of the State, and the institutional design for producing public goods." (Carnis, 2013, p. 51) It is this latter point, the institutional setting for the provision of public goods – like navigational light or ecosystem services – that is of particular relevance to this article. Thus, the following section compares the properties of lighthouses to those of ecosystems in order to identify particular conditions under which PES can be successfully provided by markets.

4. Comparing lighthouses and ecosystem services

Building upon the above sections on ecosystems (section 2) and the lighthouse example in Coase's work (section 3), the following section

compares lighthouses to ecosystem services. Table 1 presents concisely the differences between lighthouses and ecosystem service. The categories used for this distinction are deduced from the literature on Coase and on PES.

Table 1 Comparison of lighthouses and ecosystem services. If ecosystems share the properties of lighthouses, market based regulation can be successful. However, ecosystem services much often share properties of the last column. This requires mixed governance forms. (Own table)

		Lighthouse	Ecosystem Services
4.1.	**Supply function**	*Controllable, manageable*	*Partly controllable, co-production of services*
4.2.	**Dynamics**	*Static, continuous*	*Dynamic, non-continuous*
4.3.	**Property rights**	*Defined*	*Often unspecified*
4.4.	**Transaction costs**	*Low-medium*	*Medium-high*
4.5.	**Reach**	*Local*	*Local and global ecosystem services (different temporal and geographical scales)*
4.6.	**Kind of services provided**	*Life-supporting (risk-reduction); cultural service*	*Supporting, provisioning, regulating, cultural*
4.7.	**Rivalry**	*Non-rival*	*Often rival, sometimes non-rival*
4.8.	**Excludability**	*Non-excludable*	*Often non-excludable*
42251	**Monitoring**	*Technically feasible*	*Complicated*

4.1. Supply function

The supply function of a lighthouse is quite easily controllable. For economists, a production function includes labor (L) and capital (K) (McCloskey, 1985, pp. 471-474). Knowledge and materials are of course also required to build a lighthouse.

Ecosystem services, on the contrary, not only involve labor to a greater extent, but also depend on the ecosystem environment (see Figure 2): *Q(ES) = f(L, C, f(ecosystem))*. Labor here refers to a specific form of land management that should provide the ecosystem service in question. The co-production of

ecosystem services by both, human agency and ecosystem processes, make their supply function less controllable than lighthouses.

4.2. Dynamics

Lighthouses as a commodity are stable and continuous. The provision of lighthouses is an easy production function and can be quite well predicted. Ecosystem on the contrary are dynamic complex adaptive systems in which discontinuities are likely to occur (Levin, 1998). Their resilience is to be preserved from a management perspective (Holling, 1973). The fit of the institutional governance regime should thus correspond to the ecosystem dynamics (Folke et al., 2005). The prediction of ecosystem service outcomes due to specific management practices is more complicated than in the lighthouse case.

4.3. Property rights

The property rights of a lighthouse are usually well defined. The property rights structure concerning ecosystems is much more complex (Bromley, 1978). A useful classification of property rights regimes is given by Schlager and Ostrom (1992). They classify the property rights structure in five domains: access, withdrawal, management, exclusion, alienation. Groups that have access to the common pool resource, not necessarily have right to manage the resource (think about a community allowed to pass through a forest but not allowed to harvest wood). Given the complexity of property rights, it is equally complex to assign specific responsibilities for the correct management of ecosystem services. Many ecosystem services are generated by nonpoint sources with diffuse and hardly identifiable provenience (see Jack et al., 2008, p. 2467). Markets are good if property rights are well-defined (*hélas*, Coase taught us).

In the management of common pool resources, different governance options have thus developed, which are distinguished by their form of property rights: "Private, Common, State, Open access" (Ostrom, 2003). Complex property rights structures are not best handled by market.

4.4. Transaction costs

One can assume that transaction costs for the construction and the operation of lighthouses are low to medium. In ecosystem services provision, transaction costs can be considerably high. Thus there are many intermediaries who assist in the set-up of PES schemes to reduce transaction costs (see also figure 1) (Schomers et al., 2015; Vatn, 2010). Gathering information about ecosystems, services, and land management practices is

costly (Muradian et al., 2010, p. 1204): "practitioners normally face a trade-off between the need to estimate efficiency gains resulting from the intervention and the need to keep transaction costs low enough to make PES schemes feasible." Strict enforcement and monitoring schemes also render transaction costs high in the case of ecosystem management (Farley & Costanza, 2010).

4.5. Reach

While the reach of a lighthouse and its navigational light is a local public good, ecosystem services provide benefits at the local, regional and global level. If the reach of the ecosystem service is local (think about an upstream factory and downstream fishermen), a market solution is more likely to be successful than in global public goods (think about climate change mitigation). The land management practices that result in ecosystem service yields and benefits at the local level (like air quality or landscape beauty) are apt for markets. Transactions costs, in the local setting, are much smaller than for a global public good: "If PES benefits a small number of actors, incentives to free ride and transaction costs of coordinating a joint PES program are relatively low." (Engel et al., 2008, p. 667) Yet, for global public goods, markets work less efficient due to free-rider effects, high monitoring and transaction costs.

4.6. Kind of service provided

The lighthouse provides a life-supporting service with its navigational light. Lighthouses in the past had the function to provide navigational information for the safety of ships, cargo, and sailors. Yet, lighthouses also provide cultural services due to their aesthetic beauty. In the lighthouse example, we can imagine a realistic pricing system for both services: a fee collected from the ships that used the navigational light, and a fee for visitors of the lighthouse (even though there are many who can enjoy the lighthouse's beauty for free). That is an easy bundle of services provided.

Ecosystems often provide bundled services (Klain et al., 2014; Raudsepp-Hearne et al., 2010): Supporting, provisioning, regulating, cultural services are all provided by an ecosystem. "Most ecosystem services are produced as joint products (or bundles) from intact ecosystems. The relative rates of production of each service varies from system to system and site to site, and time to time" (Farley & Costanza, 2010, p. 2061) It is often difficult to disentangle these service bundles and reward for specific services. PES with service bundles are judged prevent the unintended incentive of managing an ecosystem for only one kind of service like CO2 uptake (Kemkes et al., 2010, pp. 273-274).

4.7. Rivalry

The light provided by the lighthouse is non-rival. One ship that benefits from the service of the navigational information does not hinder another ship to also benefit from the lighthouse.

That can also be the case for ecosystem services. Enjoying from the aesthetic beauty of a coastline does not diminish the opportunity of another person's experience of the coastline (of course not when the coastline is as crowded as Times Square). Yet, many ecosystem services are rival – their consumption of one person diminishes the consumption of another one.

4.8. Excludability

The lighthouse is used in economics as an illustration of a pure public good, because it is non-rival and non-excludable. The lighthouse keeper cannot direct the light to only one ship that paid the fee, and hinder other ships to also benefit from it. Nowadays, with technical improvements and GPS navigation, one can indeed imagine settings where navigational information becomes excludable.

Ecosystem services can be both excludable and non-excludable. A market situation is more likely to occur if excludability can be achieved. Yet, when we look at climate regulation for instance, the forest manager cannot exclude some third party abroad to benefit from the ecosystem service. The same is true for many other global public good ecosystem services.

4.9. Monitoring

Coase describes in detail the monitoring of the British lighthouse system. The lighthouse company (principal) was able to monitor whether the ships (agent) paid. The fee was collected in close-by harbors: "The charges were collected at the ports by agents for the lighthouses. The problem of enforcement was no different for them than for other suppliers of goods and services to the shipowner. The property rights were unusual only in that they stipulated the price that could be charged." (Coase, 1974, p. 375)

In the case of ecosystem services, monitoring is also an issue, often very costly (Meijerink, 2008). PES schemes reward for the outcome or for specific management practices (Gibbons et al., 2011). Whereas outcome-based rewards are indifferent to management practices, rewarding for specific management practices results in incomplete information concerning the outcome, i.e. the amount of ecosystem services provided. "Most PES schemes rely on observable proxies, such as actions or outcomes (e.g., the presence of buffer strips or the amount of forest cover), because direct monitoring of ecosystem service outputs is difficult or costly." (Jack et al., 2008, p. 9467)

5. Implications for the governance of ecosystem service payments

The analysis above implies to rethink governance schemes for PES and also rethink the scientific methods we use for assessing, valuing, modelling and managing ecosystem services (Van der Ploeg et al., 1987). More complex approaches are necessary (Beckenbach, 2001). The economists' proposal (get the prices right, clarify property rights, and let the market do the job) has limited applicability when dealing with complex adaptive systems: "The sustainability discourse in economics is all too often an attempt to describe systems, their evolution and their interactions in the language of neoclassical economics, although their complexity by far exceeds the capabilities of such language." (Spangenberg, 2015, p. 101) For example, multi equilibrium states can exist in ecosystems (Holling, 1973) – whereas economics is built on partial equilibrium analysis. Norgaard (2010, p. 1220) states "that the more significant one thinks our environmental problems are, the more inappropriate has been the partial equilibrium and project-by-project approach for utilizing the concept of ecosystem services."

I thus propose to deduce the following for the application of incentive-based instrument enhancing the provision of ecosystem services:

- First, if ecosystem services are lighthouses (see table 1), they can be efficiently provided by the market.
- Second, the provision of many ecosystem services is much more complex than the provision of navigational light, because ecosystems share the properties of the right column in table 1. The dynamics of ecosystem services are more complex than continuous supply and demand curves that economists are familiar with. More complex governance structures are required.
- Third, there is no single solution for the institutional structure of ecosystem service management. This goes hand in hand with Coase's argument for an economics based on empirical studies (Schmid, 2000).

One solution to the dilemma is adaptive management (Holling, 1978) proposed by a group of ecologists and social scientists (Gunderson & Holling, 2002; Gunderson et al., 1995). "[S]ustainable resource management must be an integrated and interdisciplinary process aiming at the interdependencies between institutions, environmental dynamics, economic processes, applied technologies and dominant cultures in managing and administrating natural resources." (Rammel et al., 2007, p. 10)

Adaptive management focuses on reversible management practices that encourage social learning (Berkes, 2009; Luks & Siebenhüner, 2007; Stagl, 2007). Instead of optimizing for only one ecosystem service, adaptive management seeks to enhance the resilience of the ecosystem. Such a perspective echoes the systems perspective of sustainable development

(O'Connor, 2006; Passet, 1979). "Sustaining the biosphere is not an ecological problem, nor a social problem, nor an economic problem. It is an integrated combination of all three." (Holling, 1994a, p. 58) Finally, policy interventions for the provision of ecosystem services also should consider insights from behavioral economics to avoid counter-intended results (Foxon et al., 2012; Rode et al., 2015).

6. Conclusion

This paper contributes to identify conditions under which markets can be a good institutional setting for providing ecosystem services. In the literature around PES, markets are favored by some and rejected by others (Tacconi, 2011). What is missing so far are criteria to determine what ecosystem properties require what kind of governance structure. Kemkes et al. (2010) provide first insights. Here I contribute to specify the conditions under which markets and PES schemes are effective by comparing Coase's work on lighthouses to the provision of ecosystem services.

If ecosystems share properties with lighthouses (see table 1), markets and payments can function as a tool for the provision of positive environmental externalities. However, the management of complex adaptive system on markets falls short of the co-evolutionary and co-production character of ecosystem services. In addition to the ecosystem complexities, which markets only partially can grasp, there are also equity concerns in purely market based approaches on PES (Corbera et al., 2007; Dempsey & Robertson, 2012; Muradian et al., 2013).

The findings of this article support the conclusion of Matzdorf et al. (2013, p. 62): „Pure market based solutions are only a suitable approach under consideration of lower complexity."

Finally, the article also contributes to the application of Coase's work on economics to environmental issues. Instead of reiterating the so-called "Coase theorem", this article illustrates how other, less well-known parts of Coase's work can be of relevance – for both lighthouses and ecosystems.

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[1] See also other contributions to the Ecosystem Services journal's Special Issue "Payments for Ecosystem Services and Their Institutional Dimensions: Analyzing the Diversity of Existing PES Approaches in Developing and Industrialized Countries" (Vol.6, 2013).

[2] The initial definition for PES is given by Wunder (2005) and has been revised here (Wunder, in press). The definition is challenged by some (Muradian et al., 2010; Sattler & Matzdorf, 2013; Sommerville et al., 2009).

[3] Many formulations of the "Coase theorem" exist in the literature. For an overview see Medema (2011b). Stigler (1966, p. 113) initially formulated this: "The

Coase theorem thus asserts that under perfect competition private and social costs will be equal."

[4] For a more in-depth treatment of the "Coase theorem" and its reception see the work by Steven G. Medema (Medema, 2008, 2011a, 2013, 2014).

[5] He received the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel in 1991 for his work on transaction costs (Coase, 1937) and property rights (Coase, 1960).

[6] Gomez-Baggethun and Ruiz-Perez (2011, p. 7), for example, put Coase in line with the neoliberal paradigm: „The logic of valuation, property allocation, and market-based instruments in conservation is grounded in the institutional analysis of Coase (1960) and Hardin (1968), which has fitted with the privatization policies promoted since the early 1980s and under the influence of the Chicago School (Stiglitz, 2002)."

[7] For a definition of "blackboard economics" see Coase (1988). For "humanomics" see McCloskey (2010).